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THE EFFECT OF ENVIRONMENTAL CHANGES ON THE WATER SOLUBLE CARBOHYDRATE CONTENT OF EARLY PERENNIAL RYEGRASS

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Summary

Data derived from the ADAS Herbage Quality Monitoring Survey at Reading (for the period April-June, 1977-84) were analysed in conjunction with temperature and sunshine data recorded at Reading University. Changes in the water soluble carbohydrate (WSC) content of early perennial ryegrass over 7 and 14 day periods were regressed against changes in temperature and sunshine over similar periods. Values of the ratio of actual evapotranspiration to potential evapotranspiration (AE/PE) for grass, derived from MORECS, were used to indicate the degree of water stress. For occasions with no change in the level of water stress between one period and the next, changes over 14 days gave a better regression than over 7 days during the early part of the season (prior to a temperature accumulation of 300° days above 6°C from March 1). After this threshold had been reached changes over 7 days gave the better regression. The regressions obtained give a useful improvement in the accuracy of forecasts of changes in WSC content over forecasts based on average weekly or fortnightly changes. It was not possible to derive a significant regression using temperature and sunshine data when there had been a change in the level of water stress, although the exclusion of 1984 data increased the level of significance.

Introduction

The water soluble carbohydrate content (WSC) of grass is made up of several sugars (glucose, fructose, sucrose) and fructosan. Of these fructosan forms the largest part and is an important carbohydrate in the fermentation process of silage making. MAFF has suggested that the minimum level of WSC for satisfactory fermentation is 2.5-3.0% on a fresh basis (12-15% dry matter). Consequently it is of value to a farmer to know the WSC content of grass at the time that it is cut for silage. The level of WSC in a crop can vary for a number of reasons, the principal ones being the species of grass, the stage of maturity of the crop, the rate of nitrogen application and the weather conditions prior to cutting.

The soluble carbohydrate content varies considerably between species, but in general, levels found in ryegrasses are higher than those found in other species, and it is the ryegrass species which are most commonly used in silage making. The WSC content of early perennial ryegrass usually reaches a peak during May or early June. This is thought to be related to the change from a vegetative to a reproductive growth phase. The rate of utilisation of soluble carbohydrates within the plant is largely temperature dependent, and there is considerable evidence to suggest that the temperature regime under which a grass grows has a marked effect on its WSC content (Smith (1968), Deinum (1966), Robson (1973)). The radiation level to which grass is exposed will affect the rate of production of soluble carbohydrates (Nowakowski and Cunningham (1966), Deinum (1966)).

Work by Deinum suggested that temperature changes and changes in radiation level affect both the rate of utilisation and production of soluble carbohydrates. The phenology of the crop is also an important factor governing changes in soluble carbohydrate content. Waite and Boyd (1953) noted that the development of the primary growing point from a vegetative to a floral form represents an extremely sudden demand by the plant for energy, and usually occurs during May for perennial ryegrass. Vartha (1978) also found that subjecting perennial ryegrass to water stress (- 21 bars water potential for 14 days) increased WSC levels slightly, but subsequent rewatering produced a sharp drop in WSC levels. Using Italian ryegrass, Hansen (1974) found that a water potential of - 21 bars corresponded to a relative transpiration rate (similar to the AE/PE ratio derived from MORECS) of less than 0.25, which is lower than any of the MORECS AE/PE values used in this analysis. Hence Vartha's findings may not be directly relevant here.

Since 1977 ADAS has monitored several different grass species on a weekly basis from late April until early June with a view to obtaining information about grass quality at the first cut stage. One of the measurements made is of WSC content. Samples are taken at a number of sites in each MAFF region for chemical analysis. The results from the analyses carried out at Reading have been used in this study.

Data Used

Weekly measurements of the WSC content of early perennial ryegrass taken from the Herbage Quality Monitoring Survey data for 1977-84 were used. These were corrected from the "as received" basis to 20% equivalent dry matter using actual dry matter percentages from the survey data. Meteorological data were obtained from the Reading University site at Whiteknights (about 3 miles distant from Coley Park). Weekly mean air temperatures were calculated from daily maximum and minimum values, and accumulated temperatures above 6°C from March 1 were summed up to the date of sampling. It is assumed for the purpose of this analysis that the start of spring growth of grass occurs above 6°C (Roy 1972). Sunshine hour totals were used since no solar radiation measurements are available from Whiteknights and the distribution of sites measuring solar radiation over the UK is poor. Cowley (1978) suggested an improved empirical relationship between sunshine hours and global radiation and thus changes in sunshine hours have been used as an approximation to changes in global radiation. Estimates of the change in level of plant water stress were made using MORECS data for Hurley, the nearest station to Reading for which this was available. The ratio of actual evapotranspiration to potential evapotranspiration for grass was calculated from this (AE/PE). A change in water stress was defined as a change in AE/PE $\geq$.01.

Method of Analysis

Changes in mean temperature and hours of sunshine over 7 and 14 day periods were calculated from the Whiteknights data, and the values of AE/PE calculated from MORECS were differenced for the same periods to indicate changes in water stress. Changes in WSC content over the same periods were calculated using the Herbage Quality Monitoring Survey data. The values occurring prior to temperature accumulations of 300°C days above 6°C were plotted against temperature changes (Figs 1A and 1B). Plots against sunshine and AE/PE changes did not show such good relationships. For temperature accumulations of more than 300°C days above 6°C the relationship between WSC content change and environmental changes was not as clear. The threshold of 300°C days was assumed to mark the phenological change from vegetative to reproductive growth which precedes the plant's maximum demand for carbohydrates. This probably corresponds to the stage

FIG. 1A 7 DAY CHANGE IN %WSC V. 7 DAY CHANGE IN TEMPERATURE

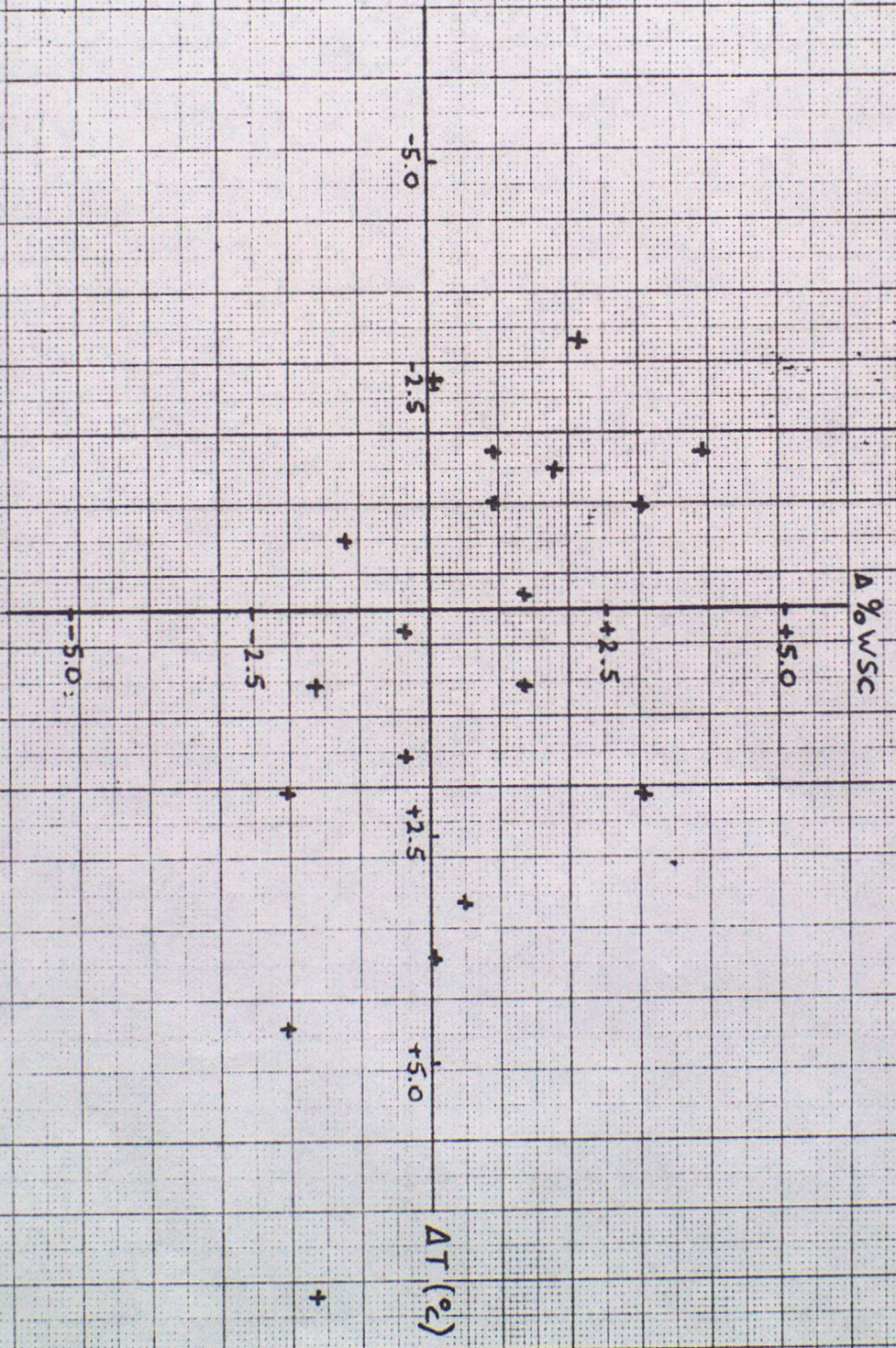
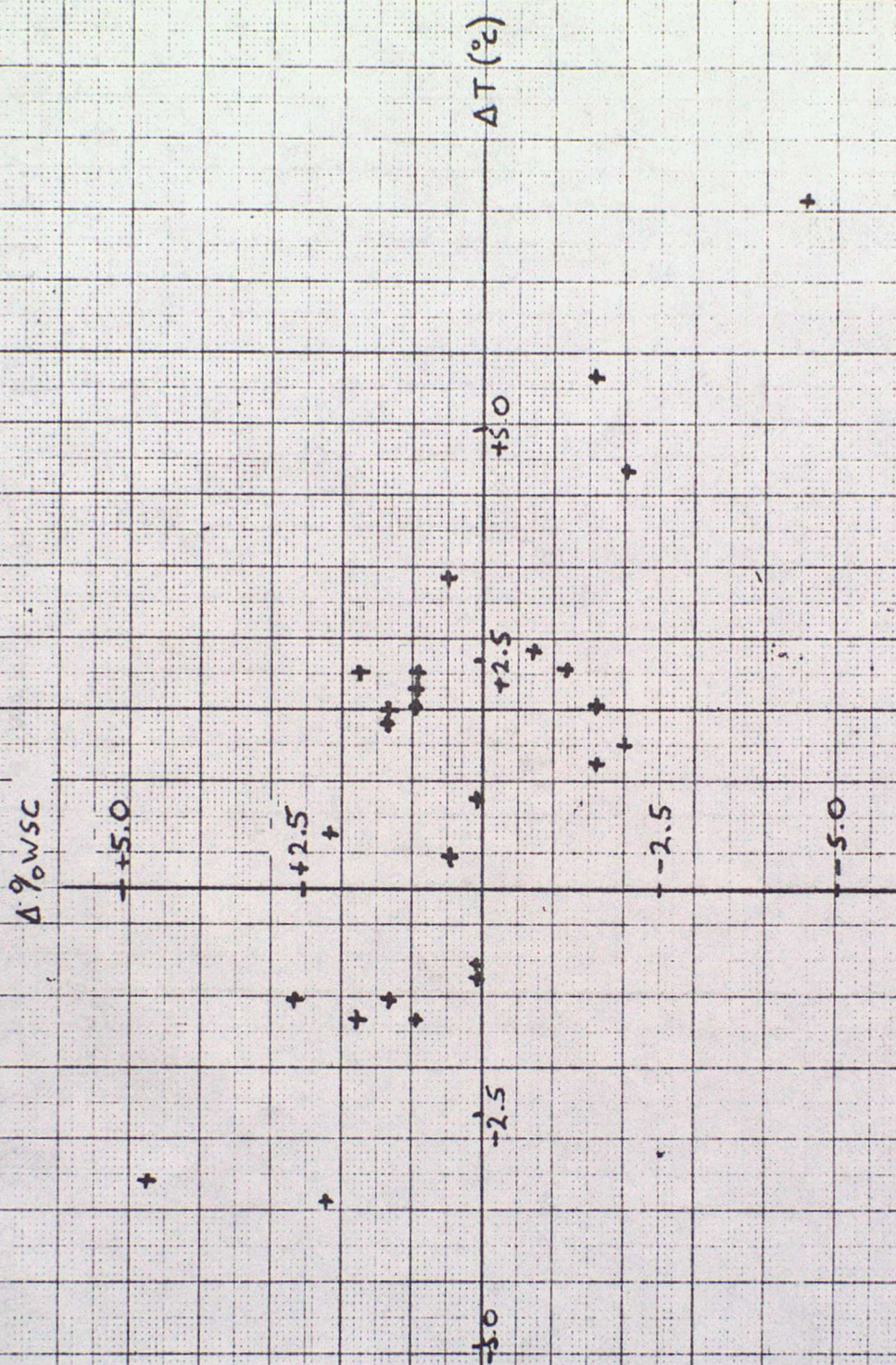


FIG. 18 14 DAY CHANGE IN %WSC V. 14 DAY CHANGE IN TEMPERATURE



in cereal growth at which the terminal spikelet is produced. Hough (personal communication) has suggested that this point is reached for winter wheat after a temperature accumulation of approximately 1000° days above 0°C from a mid-October sowing date. Using estimated mean accumulated temperatures for Whiteknights, calculated by Thom's method (1966), a mean date of mid-April is obtained for an accumulation of 1000° days above 0°C starting from mid-October. Mean temperature accumulations above 6°C over this same period (mid-October to mid-April) total about 300° days (Table 1). For a perennial crop, such as grass there is no equivalent to an autumn sowing date, so temperature accumulations were taken from March 1.

If it is assumed that the thermal time requirement to reach the reproductive stage of growth is similar for both cereals and grass, then temperature accumulations of 300° days above 6°C, taken from March 1 may be used to indicate the time required by grass to reach this stage of development.

TABLE 1

Mean air temperature accumulations at Reading (Whiteknights) from
15 October to 15 April (1951-80)

	Nov. 1	Dec. 1	Jan. 1	Feb. 1	Mar. 1	Apr 1	Apr 15
Above 0°C	150	351	505	634	759	942	1060
Above 6°C	62	109	146	187	219	265	299

The data were therefore divided into two groups, one comprised of values which occurred prior to the 300° day threshold, and one of values which occurred after this. A multiple regression analysis was carried out on each group of data, for both 7 day and 14 day changes, against change in temperature, change in sunshine hours and change in ratio of AE/PE. Both 7 and 14 day periods were chosen because the response times of the production and utilisation processes in the plant to changes in temperature and radiation levels are not known.

Results

Changes over 14 day periods provided better regressions than 7 day changes for occasions before 300° days. The use of 7 day changes for occasions after 300° days gave a small improvement over 14 day changes. The effects of changes in water stress on WSC content proved to be unpredictable. Thus the two groups of data were separated into occasions where the ratio of AE to PE had changed during the previous 14 days (indicating a change in water stress over the period) and those where it had not. The multiple regressions obtained for those occasions with no change in water stress were more significant than those where there had been a change in water stress. As a comparison, average 7 and 14 day changes in WSC content were calculated on a weekly basis for the period 1977-84. The standard deviation about this average is given with the standard error of the estimate for each regression. For occasions prior to a 300° day temperature accumulation the following regressions were obtained:-

$$\Delta WSC = 1.18 + 0.11\Delta S - 0.55\Delta T \quad (P < .005) \quad (1A)$$

using 14 day changes, and $(r = 0.82)$
 (standard error of est. ± 1.1)
 (S.D. about average change ± 1.7)

$$\Delta WSC = 0.57 + 0.08\Delta S - 0.35\Delta T \quad (P < .1) \quad (1B)$$

using 7 day changes $(r = 0.55)$
 (standard error of est. ± 1.5)
 (S.D. about average change ± 1.5)

where ΔWSC is change in % WSC content from one period to the next

ΔS is change in mean daily sunshine from one period to the next

ΔT is change in mean temperature from one period to the next

For occasions after 300^o days had been reached

$$\Delta WSC = 0.17 + 0.46\Delta S - 0.43\Delta T \quad (P < .025) \quad (2A)$$

using 14 day changes, and $(r = 0.75)$
 (standard error of est. ± 1.2)
 (S.D. about average change ± 1.7)

$$\Delta WSC = -0.29 + 0.49\Delta S - 0.08\Delta T \quad (P < .01) \quad (2B)$$

using 7 day changes $(r = 0.78)$
 (standard error of est. ± 0.6)
 (S.D. about average change ± 1.0)

Thus in non-water stress situations changes in sunshine and temperature generally give better estimates of weekly or fortnightly variations in WSC content than average changes alone.

For occasions where there had been a change in water stress between one 14 day period and the next, the change in AE/PE was used as an additional independent variable. A significant regression could not be obtained for occasions having a temperature accumulation of less than 300^o days, although the exclusion of 1984 data gave a regression significant at the $P < .05$ level.

1984 was exceptional in that April and early May were very dry producing an unusually high level of water stress for that time of year. This was followed by a wet spell in mid-May which reduced the level of water stress again. It was the only year during the period considered which produced this sequence of conditions. The exclusion of $\Delta AE/PE$ from the regression did not improve the level of significance, but did reduce the standard error of the estimate by a small amount.

There were only 9 occasions during the period considered with both temperature accumulations greater than 300^o days and a change in level of water stress, and the most significant regression that could be obtained was for 14 day changes, where once again the exclusion of 1984 data improved the level of significance. However, the regression was significant at only the $P < .05$ level.

Discussion

The WSC content of grass clearly depends on several environmental factors as well as crop phenology. Grass phenology alone would suggest an initial rise in WSC level following the start of spring growth and the increasing leaf area available for photosynthesis. With ryegrasses this continues throughout the period of growing point elongation until just prior to flower emergence. The demand for carbohydrate reserves which the initiation of flowering imposes on the plant would suggest that this is probably the point at which peak WSC

levels would be reached. After this the onset of leaf senescence and the carbohydrate demands of the forming seed head would result in a steady decline in WSC level. Fig. 2 shows average WSC levels (at 20% DM equivalent) for early perennial ryegrass for 1977-84. It can be seen that the amount of year to year variation increases until mid-May, which reflects the variation in timing of the WSC "peak" each year. After this, average WSC content falls, and the year to year variation decreases by a factor of about 4.

Superimposed on this natural progression of events are changing environmental conditions. In periods of cool weather the conversion of soluble carbohydrate into structural carbohydrate will be slowed, and an increase in WSC levels, or "stored" carbohydrates, would be observed. The regressions obtained indicate that WSC change is negatively related to temperature change. However, changes in water stress have a marked effect on this process which is still unclear at present. With the exclusion of data for 1984, soluble carbohydrate changes appear to be negatively related to changes in water stress, thus differing from Vartha's findings. It should be remembered, however, that the degree of water stress imposed during his experiments almost certainly exceeded that suggested by mean AE/PE values derived from MORECS, although it may have been representative of maximum levels experienced by a crop during periods of high evaporative demand. These conditions would normally only occur for a short period each day, whereas Vartha maintained low water potentials continuously for a period of 14 days.

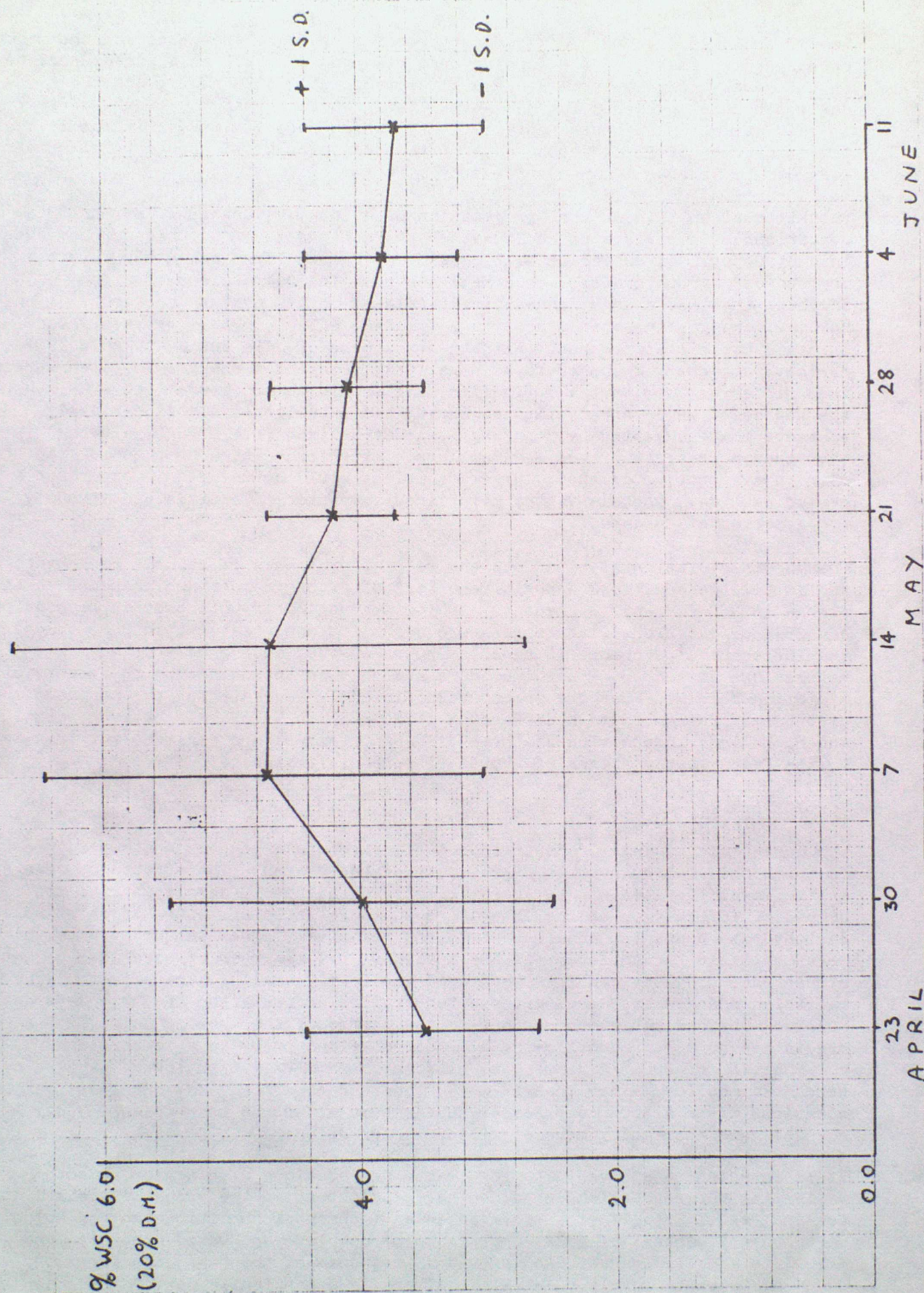
Changes in radiation level affect the rate of synthesis of soluble carbohydrate, and in all the equations a positive effect of a change in sunshine hours on the change in WSC content is present. It is interesting to note that in regressions 2A and 2B (for occasions with temperature accumulations greater than 300 ° days) the influence of a change in sunshine hours is very much greater than in regressions 1A and 1B. Sunshine hours are only an approximation to amounts of radiation received, but are probably sufficiently accurate for the purposes used here. Deinum found a difference of 20%-25% in WSC levels between normal and high light intensities at three different temperature regimes, but this was in the fairly early stages of growth of perennial ryegrass.

Conclusions

The dependence of the WSC content of early perennial ryegrass on temperature changes is quite clear throughout the early part of the season. The effects of changes in the level of water stress are difficult to interpret, due in part to the dearth of information in the literature on the effects of water stress on soluble carbohydrate contents, and in part to the relatively small amount of data which were available for this part of the analysis. (The number of occasions of water stress occurring between April and June was fairly small). The effect of radiation changes increases after a temperature accumulation of 300 ° days has been reached, which roughly corresponds to the change of the growing point from a vegetative to a reproductive phase. For occasions prior to a temperature accumulation of 300 ° days more significant regressions, with lower standard errors, were obtained for 14 day changes in WSC content than for 7 day changes. For occasions after a 300 ° day temperature accumulation has been reached 7 day WSC changes gave a slightly more significant regression.

It is intended to analyse data for some other stations with a view to both validating the regressions obtained here and extending the amount of data available for analysis. The effect of changes in environmental conditions on the soluble carbohydrate content of grass appears to be complex, and would probably lend itself to a modelling approach provided that some of the basic processes could be more accurately quantified. There is a particular need for further work on the effects of water stress on soluble carbohydrate synthesis and utilisation, particularly during the vegetative and early reproductive growth stages.

FIG. 2 AVERAGE AND STANDARD DEVIATION OF WSC CONTENT FOR EARLY PERENNIAL RYEGRASS AT READING. (1977-84)



It is hoped that this method of predicting short term changes in WSC content can be used to update measurements made during the ADAS Herbage Quality Monitoring Survey. At present samples are taken weekly and there is a delay of several days before the results are published or broadcast. Thus prediction of 7 day changes could be used to update these values, based on sunshine and temperature observations during the 7 day period following each sampling. Predictions of 14 day changes would be based on these observations plus medium range forecasts of temperature and sunshine to produce a 7 day forecast of WSC content based on survey results from the previous week.

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